

1 **CLAIMS**

2 1. In a system in which data transmissions on a multi-conductor signal  
3 path produce current flow based on the value of the data transmitted, a method of  
4 reducing change in current flow between successive data transmissions, the  
5 method comprising:

6 encoding data values represented by sets of N bits to produce  
7 corresponding sets of M symbols, each set of M symbols representing a plurality  
8 of bits, and each set of M symbols being selected to produce a current flow within  
9 a predetermined range of current flows; and

10 transmitting the sets of M symbols.

11  
12 2. A method as recited in claim 1 wherein each set of M symbols  
13 represents more than N bits.

14  
15 3. A method as recited in claim 1 further including decoding the data  
16 values from the sets of M symbols.

17  
18 4. A method as recited in claim 1 wherein each conductor in the multi-  
19 conductor signal path supports four different symbols.

20  
21 5. A method as recited in claim 1 wherein each symbol represents two  
22 bits.

1           **6.**     A method of multi-level signaling, the method comprising:  
2           determining whether signal current required to transmit a data element is  
3           within a predetermined range of current values; and

4           encoding the data element if the current required to transmit the data  
5           element is not within the predetermined range of current values, wherein the data  
6           element is encoded such that the signal current required to transmit the data  
7           element is within the predetermined range of current values.

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9           **7.**     A method as recited in claim 6 further including adding a signal to  
10          the encoded data element to indicate any encoding of the data element.

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12          **8.**     A method as recited in claim 6 further including transmitting the  
13          encoded data.

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15          **9.**     A method as recited in claim 6 further including transmitting the  
16          encoded data across multiple conductors, wherein each conductor supports four  
17          different signal levels.

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19          **10.**    A method as recited in claim 6 wherein the data element is a byte of  
20          data.

21  
22          **11.**    A method as recited in claim 6 wherein encoding the data element  
23          includes incrementing each symbol of the data element.

1           **12.**    A method as recited in claim 6 wherein encoding the data element  
2 includes repeatedly incrementing all bits of the data element until the signal  
3 current required to transmit the data element is within the predetermined range of  
4 current values.

5  
6           **13.**    One or more computer readable media storing computer-executable  
7 instructions that, when executed on one or more processors, perform the method of  
8 claim 6.

9  
10          **14.**    A method of encoding a set of bits for transmission in a system that  
11 supports at least four discrete signal levels on a transmission medium, the method  
12 comprising:

13           encoding a first group of  $N$  bits of the set of bits using a first encoding  
14 scheme to generate a first encoded bit set that includes at least  $N+1$  bits, wherein  
15 the first encoded bit set has a first weighting corresponding to state of the at least  
16  $N+1$  bits of the first encoded bit set;

17           encoding a second group of  $N$  bits of the set of bits using a second  
18 encoding scheme to generate a second encoded bit set that includes at least  $N+1$   
19 bits, wherein the second encoded bit set has a second weighting corresponding to  
20 state of the at least  $N+1$  bits of the second encoded bit set;

21           when a combination of the first weighting and the second weighting is  
22 within a predetermined weighting range, combining the first and second bit sets to  
23 produce an output symbol set;

24           when the combination of the first weighting and the second weighting is  
outside of the predetermined weighting range:

1 encoding the second group of N bits of the set of bits using a third  
2 encoding scheme to generate a third encoded bit set that includes at least  
3 N+1 bits, wherein the third encoded bit set has a third weighting that is  
4 different from the second weighting; and  
5 combining the first and third encoded bit sets to produce the output  
6 symbol set.

7  
8 **15.** A method as recited in claim 14 wherein the set of bits represents  
9 four input symbols, wherein each of the input symbols represents a most-  
10 significant bit and a least-significant bit, and wherein the output symbol set  
11 includes five output symbols, such that each of the output symbols represent two  
12 bits.

13  
14 **16.** A method as recited in claim 15 wherein the first group of bits  
15 includes the most-significant bits of the input symbols and the second group of  
16 bits includes the least-significant bits of the input symbols.

17  
18 **17.** A method as recited in claim 14 wherein:  
19 the first weighting is determined based on a number of binary ones included  
20 in the first encoded bit set multiplied by a first variable;  
21 the second weighting is determined based on a number of binary ones  
22 included in the second encoded set multiplied by a second variable; and  
23 the third weighting is determined based on a number of binary ones  
24 included in the third encoded set multiplied by the second variable.

1           **18.**   A method as recited in claim 17 wherein the predetermined  
2 weighting range spans a range equal to a value of the second variable.

3  
4           **19.**   A method as recited in claim 14 wherein the first encoding scheme  
5 is such that the first bit set includes either a first number of binary ones or a  
6 second number of binary ones, wherein when the first encoded bit set includes the  
7 second number of ones, the combination of the first and second encoded bit sets is  
8 outside of the predetermined weighting range.

9  
10          **20.**   A method as recited in claim 14 wherein when the second group of  
11 N bits contains all binary zeros, a first exception bit set is generated, wherein the  
12 output symbol set is produced by combining the first exception bit set with the  
13 first encoded bit set, wherein the output symbol set has a weighting that is within  
14 the predetermined weighting range.

15  
16          **21.**   A method as recited in claim 20 wherein, for all cases other than the  
17 case where the second group of N bits is all zeros, the second encoded bit set for a  
18 corresponding second group of N bits is the bit-wise inverse of the third encoded  
19 bit set for the corresponding second group of N bits.

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1           **22.**     A method as recited in claim 20 wherein when the first and second  
2 groups of N bits both contain all zeros, a second exception bit set is generated as  
3 the first encoded bit set and a fourth encoded bit set is generated, wherein the  
4 second exception bit set and the fourth encoded bit set are combined to produce  
5 the output symbol set, wherein the fourth encoded bit set is generated such that  
6 weighting of the output symbol set is within the predetermined weighting range.

7  
8           **23.**     A method as recited in claim 14 further comprising transmitting  
9 symbols in the output symbol set in parallel over a plurality of lines.

10  
11           **24.**     A method as recited in claim 23 wherein each line of the plurality of  
12 lines is a communication medium that supports the at least four signal levels.

13  
14           **25.**     A method as recited in claim 14 further comprising:  
15           serializing at least a portion of the symbols of the output symbol set to  
16 produce a serial stream of symbols; and  
17           serially transmitting the serial stream of symbols over a line.

18  
19           **26.**     A method as recited in claim 25 wherein the line is a communication  
20 medium that supports the at least four discrete signal levels.

1       **27.**     A method as recited in claim 14 wherein the system supports at least  
2 eight discrete signal levels on the transmission medium, wherein the set of bits  
3 represents a first number of input symbols, wherein each of the input symbols  
4 represents three bits, and wherein each symbol in the output symbol set represents  
5 three bits.

6  
7       **28.**     A method as recited in claim 14 wherein the system supports at least  
8 M discrete signal levels on the transmission medium, wherein the set of bits  
9 represents a first number of input symbols, wherein each of the input symbols  
10 represents  $\log_2 M$  bits, and wherein each symbol in the output symbol set  
11 represents  $\log_2 M$  bits.

12  
13       **29.**     A method comprising:  
14       receiving a data value to be transmitted across a plurality of conductors  
15 using current mode drivers, wherein each of the plurality of conductors supports  
16 multiple signal levels;

17       determining whether a sum of the currents required to transmit the data  
18 value is within a predetermined range of current values;

19       transmitting the data value if the sum of the currents is within the  
20 predetermined range of current values; and

21       encoding the data and transmitting the encoded data if the sum of the  
22 currents is not within the predetermined range of current values, wherein the data  
23 is encoded such that the sum of the currents is within the predetermined range of  
24 current values.

1           **30.**     A method as recited in claim 29 wherein the predetermined range of  
2 values reduces current changes between successive data values.

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4           **31.**     A method as recited in claim 29 wherein the received data value is a  
5 byte of data.

6  
7           **32.**     A method as recited in claim 29 wherein encoding the data value  
8 includes incrementing each symbol of the data value.

9  
10          **33.**     A method as recited in claim 29 wherein encoding the data value  
11 includes incrementing all bits of the data value until the current required to  
12 transmit the signal is within the predetermined range of current values.

13  
14          **34.**     A method of decoding a set of bits in a system that is capable of  
15 receiving at least four discrete signal levels on a transmission medium, the method  
16 comprising:

17           decoding a first group of bits using a first decoding scheme to generate a  
18 first decoded group of bits;

19           decoding a second group of bits using a second decoding scheme to  
20 generate a second decoded group of bits;

21           analyzing the first group of bits to determine whether the first group of bits  
22 represents a first exception bit set or a second exception bit set;

23           if the first group of bits represents a first exception bit set, then replacing  
24 the first decoded group of bits with the second decoded group of bits and replacing  
25 the second decoded group of bits with a first predetermined value; and



1 if the first group of bits represents a second exception bit set, then replacing  
2 the first decoded group of bits with a second predetermined value and replacing  
3 the second decoded group of bits with the first predetermined value.  
4

5 **35.** A method as recited in claim 34 wherein the bits of the first  
6 predetermined value are all zeros and the bits of the second predetermined value  
7 are all zeros.  
8

9 **36.** A method as recited in claim 34 further comprising deserializing a  
10 serial stream of symbols to identify the first group of bits and the second group of  
11 bits.  
12

13 **37.** An apparatus comprising:  
14 a plurality of multi-level output drivers coupled to a plurality of conductors;  
15 and  
16

17 an encoder configured to receive a data element, the encoder having outputs  
18 coupled to the plurality of multi-level output drivers, the encoder encoding the  
19 data element, if necessary, to maintain the signal current required to transmit the  
20 data element within a predetermined range of values.  
21

22 **38.** An apparatus as recited in claim 37 wherein the encoder further adds  
23 a symbol to the data element to indicate any encoding of the data element.  
24  
25

1           **39.**    An apparatus as recited in claim 37 wherein the plurality of  
2 conductors form a transmission channel.

3  
4           **40.**    An apparatus as recited in claim 37 wherein the encoder encodes the  
5 data element by incrementing each symbol of the data element.

6  
7           **41.**    An apparatus as recited in claim 37 further including transmitting  
8 the encoded data element across the plurality of conductors.

9  
10          **42.**    An apparatus as recited in claim 37 wherein the plurality of multi-  
11 level output drivers are multi-level current drivers.

12  
13          **43.**    An apparatus as recited in claim 37 further including a decoder  
14 coupled to the encoder, wherein the decoder decodes the signal received from the  
15 plurality of multi-level output drivers.

16  
17          **44.**    An apparatus to encode a set of bits for transmission in a system that  
18 supports at least four discrete signal levels on a transmission medium, the  
19 apparatus comprising:

20           a first encoder configured to encode a first group of N bits of the set of bits  
21 using a first encoding scheme, wherein the first encoder generates a first encoded  
22 bit set that includes at least N+1 bits, wherein the first encoded bit set has a first  
23 weighting corresponding to state of the at least N+1 bits of the first encoded bit  
24 set;

1 a second encoder configured to encode a second group of N bits of the set  
2 of bits using a second encoding scheme, wherein the second encoder generates a  
3 second encoded bit set that includes at least N+1 bits, wherein the second encoded  
4 bit set has a second weighting corresponding to state of the at least N+1 bits of the  
5 second encoded bit set;

6 a first comparator coupled to the first encoder and configured to determine  
7 whether the first weighting has a first predetermined value; and

8 a second comparator coupled to the second encoder and configured to  
9 determine whether the second weighting has a second predetermined value.

10  
11 **45.** An apparatus as recited in claim 44 further comprising a logic gate  
12 coupled to the first comparator and the second comparator such that the logic gate  
13 determines whether the first weighting has the first predetermined value.

14  
15 **46.** An apparatus as recited in claim 45 wherein the logic gate further  
16 determines whether the second weighting has the second predetermined value.

17  
18 **47.** An apparatus to decode a set of bits received by a system, the  
19 apparatus comprising:

20 a first decoder configured to decode a first group of bits using a first  
21 decoding scheme, wherein the first decoder generates a first decoded group of bits;

22 a second decoder configured to decode a second group of bits using a  
23 second decoding scheme, wherein the second decoder generates a second decoded  
24 group of bits;

1 a first comparator coupled to the first decoder and configured to determine  
2 whether the first group of bits represents a first exception bit set;

3 if the first group of bits represents the first exception bit set, then the first  
4 decoded group of bits is replaced with the second decoded group of bits and the  
5 second decoded group of bits is replaced with a first predetermined value;

6 a second comparator coupled to the first decoder and coupled to determine  
7 whether the first group of bits represents a second exception bit set; and

8 if the second group of bits represents the second exception bit set, then the  
9 first decoded group of bits is replaced with a second predetermined value and the  
10 second decoded group of bits is replaced with the first predetermined value.

11  
12 **48.** An apparatus as recited in claim 47 wherein the bits of the first  
13 predetermined value are all zeros and the bits of the second predetermined value  
14 are all zeros.

15  
16 **49.** An apparatus as recited in claim 47 further comprising a deserializer  
17 coupled to the first decoder and the second decoder, wherein the deserializer is  
18 configured to deserialize a serial stream of symbols.